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Design of a Fuel Free Electric Vehicle Using Fuzzy Logic for Pollution Control

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Abstract

Nowadays the existing vehicles, which run through fuel, are produces excess pollution. To avoid this problem we proposed a new method called Fuzzy based Electric Vehicle (FEV) without using fuel. An advanced battery system and drive is integrated through fuzzy controller. The design of automatic charging system meets different design parameters and automatically starts and stops the charging system, eliminating the need for driver involvement. The proposed system contains two turbines with an alternator, one for charging the auxiliary battery and the other one for two purposes: for charging the HV battery system and drive the motor directly if the speed exceeds forty kilometers. The power generation system is present in the top of the vehicle. Compared with other vehicle technology, the FEV presented in this paper overcome the future fuel crisis. Simulation result shows that the electric vehicles eliminate total diesel exhaust and help for healthy generation.

Keywords : electric vehicle; battery charging; fuzzy controller; pollution control

1. Introduction

The world cannot live without oil. It will be more and more expensive and environmentally destructive to extract the remaining supply. As the world population grows, the effects of the pollution they produce become more and more destructive. The cost of controlling these pollutants is increasing every day. Mercury has poisoned our fisheries and acid rain from sulphur has destroyed forests and lakes. Acidified oceans have damaged coral reefs all over the world. Oil sands, shale mining and mountaintop removal

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pollute our water and leave a wasteland in their wake. Fossil fuels were once so cheap that we quickly developed wasteful ways that made us addicted to them. Now that the easy deposits have been depleted, it becomes more and more expensive and destructive to extract them from the earth. Electric vehicles typically have less noise pollution than an internal combustion engine vehicle, whether it is at rest or in motion. An electric vehicle emits no tailpipe CO2 or pollutants such as NOx, NMHC, and CO.

Hybrid vehicle is the combination of linear engines and linear alternator that are explained in [1]. The operation of each component of the system has been examined and the design procedure for the alternator has been outlined. The design and analysis of the proof of concept model has indicated areas in which the alternator can be improved, such as decreasing the winding resistance for improved efficiency and lowering the weight of the translator for increasing the speed of operation. The permanent magnet generator output is rectified and passed through a buck converter before connection to the main DC bus bar for getting maximum engine efficiency [2]. The choice of power electronic interface dictates design details in the generator and the exact level of output voltage. With the buck converter a high output voltage is required and this necessitates the use of a double layer winding. A self-reconfigurable electric motor controller for hybrid vehicle is proposed in [4]. The failure of current sensors are easily detected and estimate the phase current using Luenberger type observer The developed observer is implemented on a 3-phase four pole permanent magnet motor with digital signal processor. The bi-directional ac-dc converter for plug-n hybrid vehicle is presented in [5]. The converter topologies are analyzed in detail and the combined topology is more advantages with respect to cost and weight.

The fuel consumption and emission of hybrid vehicle and the energy management strategy is studied in [6]. From the starting general optimal control problem a new cost functional is defined and account for electrical energy supplied from the grid. Design and implementation of an electric drive system for in-wheel motor using Matlab SIMULINK model is developed and the performance values are calculated in [7]. The hub type drive has more advantages and it can be used in vehicle technology.

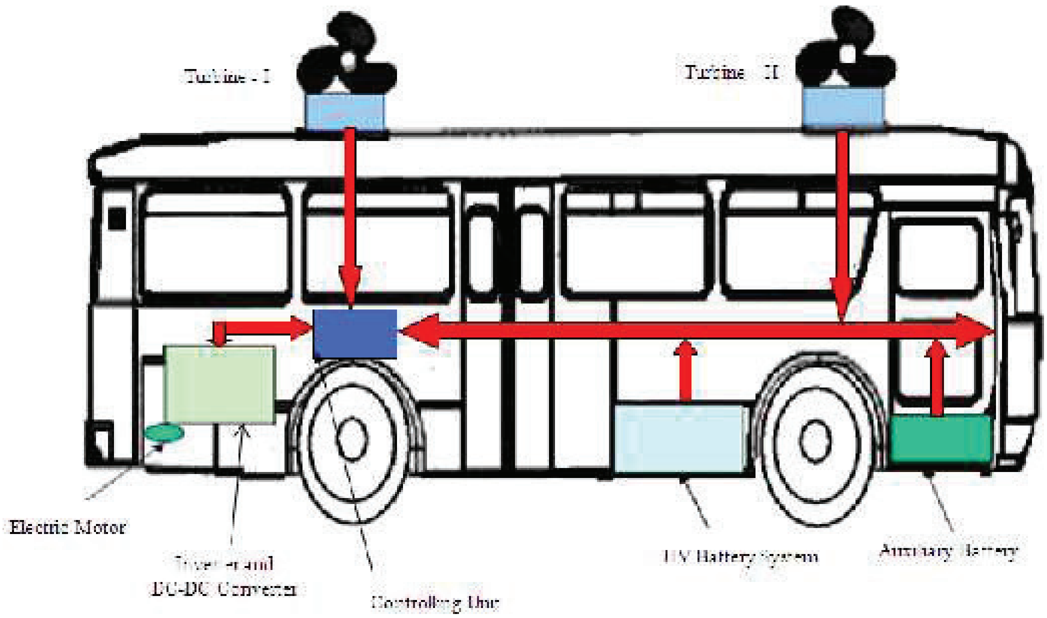


Fig. 1. Different components present in the vehicle

The fuel consumption and emission of hybrid vehicle and the energy management strategy is studied in [6]. From the starting general optimal control problem a new cost functional is defined and account for electrical energy supplied from the grid. Design and implementation of an electric drive system for in-wheel motor using Matlab SIMULINK model is developed and the performance values are calculated in [7]. The hub type drive has more advantages and it can be used in vehicle technology.

Most of the developed countries have incorporated electric vehicles for pollution controlling purpose. We believe that the implemented system has many advantages and can be adopted by developing countries at all levels. The rest of this paper is organized as follows: section 2 describes the configuration of electric vehicle; section 3 describes the model of electric vehicle; section 4 explains the performance evaluation of FEV; and finally, conclusion is discussed in section 5.

2. Electric Vehicle Configuration

The advanced induction motor and the driver system are developed specifically for vehicle use. Fuzzy logic based power electronic system with sensors, high power Switched Mode Rectifier (SMR) and inverters for fast charging of the batteries. Various components present in the bus are shown in figure 1. In this system we are incorporating two different capacity turbines with gear arrangement and variable speed alternators, one is for charging the HV batteries automatically if the vehicle is under running condition as shown in figure 2, and turbine-II is for two purposes: charging the auxiliary battery and directly run the motor if it exceeds 40 kilometer speed. The motor is taking power from the battery at the starting time and it will automatically switch over to direct supply after attaining a speed of 40-kilometers as shown in figure 3. The controlling operations are maintained by the fuzzy controller, which is integrated within the system.

The alternator-I is a 15KW capacity to recharge the battery system. The wind turbine rotor is connected to the induction generator through a gearbox. The induction generator has many advantages like robustness, mechanical simplicity and low cost. The control system is used to ensure that the proper operation of turbine under all conditions. By using a soft starter the output of generator is connect to the load. The induction generator consumes reactive power while generating active power. The active power P_a of electrical power is given in equation 1.

$$P_a = \sqrt{3}\, V_{eff} I_{eff} \cos\phi \tag{1}$$

Where, V_{eff} is r.m.s line to line voltage, cosØ is the power factor and the reactive power (P_r) is given in equation 2, where I_{eff} is the line current.

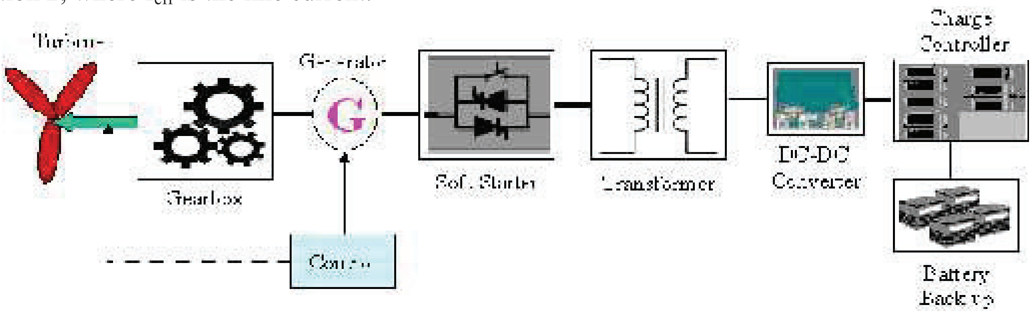


Fig. 2 . Block diagram of Turbine-I control system for charging

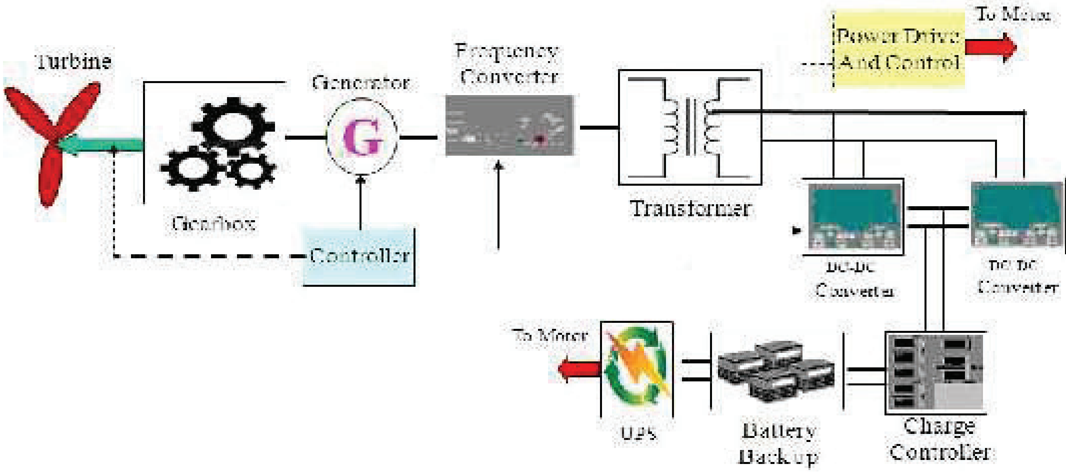


Fig. 3. Block diagram of Turbine-II control system for charging and direct drive

$$P_r = \sqrt{3}\, V_{eff} I_{eff} \sin\phi \tag{2}$$

We are including a variable speed wind turbines for reducing mechanical stress and improve the power quality. The capacity of turbine-II is around 25KW and the output power is maintained with the help of a transformer. Frequency converters become more significant control of wind turbines. The most important properties of frequency converter are 1.The rotor behaves as energy storage 2. Loads on the gear and drive train can be reduced. 3. The acoustic emission noise can be reduced. 4. The power absorbed at low wind speed can be improved. Frequency converter can control the reactive power such that the power quality can be improved. The voltage stability is improved and flicker level is reduced.

Different battery types and technologies have emerged and become more economical. Lead acid, CNG, Nickel Metal Hydride, Zebra are extensively used in electric vehicles [8], [9]. We are incorporating Zebra batteries because of the storage capacity, good performance and less cost. The battery is completely sealed and includes terminal conductors that are connected through a battery management system. The

FEV contains different subsystems namely power inverter controller, drive and control unit, and speed measurements and control are integrated with the fuzzy controller.

3. Electric vehicle System Model

3.1 Electrical Design Equation

The current density due to the magnet, J_m is given by

$$J_m = \frac{4}{\tau}\frac{B_r}{\mu_o \mu_r}\sin\frac{W_n}{2}M_d \quad \text{A/m}^2 \tag{3}$$

Where B_r is the remenence of magnet, τ is the pole pitch, M_d is the magnet diameter and $W_n = \Pi n/\tau$ described by [10]. The distribution of flux density is almost sinusoidal and is given by

$$B_x = \left[\frac{J_m \mu_o}{W_n}\frac{\sinh W_n t_m}{\sinh W_n g/2}\right]\cos W_n x \tag{4}$$

The magnetic flux density distribution around each magnet with radius r from the center is described by

$$\phi_A = 2\Pi B\left[\left(\frac{1}{u_1}\right)^2(\cos u_1 - 1) + \frac{1}{u_1}(r \sin u_1 r)\right] \tag{5}$$

The armature coil is concentrated at its axial position then the total flux linkage is given by $\phi_f = \frac{N}{3}(\phi_A)$ and the coil emf is $E_c = \frac{2\Pi}{\sqrt{2}} f\phi_f$

The three phase generator output is rectified and directly used for charging batteries or connect to the inverter. The equivalent circuit of battery charger is shown in fig. 4

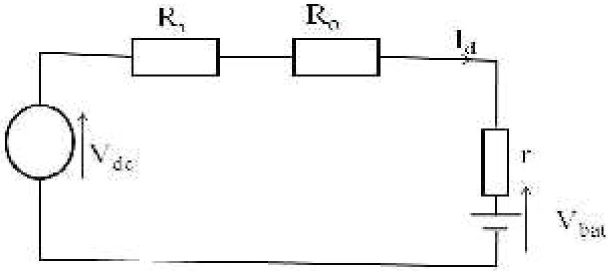


Fig. 4. Equivalent dc circuit for battery charging

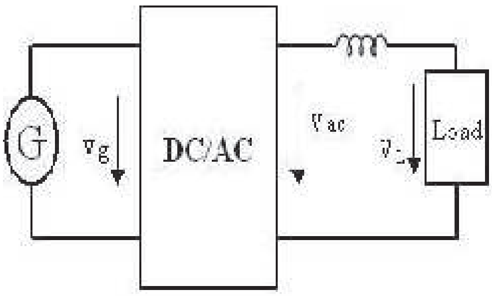


Fig 5. DC/AC inverter model

The internal resistance and the open circuit emf is modeled for the battery and the generator is represented by its open circuit emf and equivalent overlap resistance [11]. The effective resistance of the armature is twice the phase resistance. $R_{dc} = 2R_p$. So the overlap resistance is given by $R_o = {}^{3}\!/_{\pi} WL_p$. The open circuit emf is related to the phase voltage by

$$V_d = \frac{3\sqrt{2}V}{\pi} = 2.34 V_p \tag{6}$$

$$I_d = \frac{V_d - V_{bat}}{R_{dc} + R_o + r} \tag{7}$$

Now the battery terminal voltage is

$$V_d = \mathrm{V}_{do} - I_d R_{dc} - I_{dR_o} \tag{8}$$

3.2 Power Inverter Model

In this paper, only a simple model of a DC/AC inverter is considered for the following reasons: the dynamic time constant of inverters is of the order of microseconds or at the utmost milliseconds. The time constants for the reformer and stack are of the order of seconds. The model of the inverter is given in [9], where the output voltage and output power are controlled using the inverter modulation index and the phase angle θ of the AC voltage. Considering the generator as a source, the inverter and load connection is shown in Fig. 5.

V_o - AC output voltage of the inverter (V)
M_i - modulation index of inverter
Ø - phase angle of the AC voltage (rad)
P_o - the inverter output power (W)
P_{re}- reactive power of the inverter (W)
V_L - load voltage (V)
X_L- reactance of the line to the load
I_L - load current (A)
θ - load phase angle (rad)
P_L - load power (W)
The output voltage in terms of modulation index is given by

$$\mathrm{V_o} = \mathrm{m_i}\, \mathrm{V_{gen}} \tag{9}$$

The output power as a function of modulation index, the phase angle ϕ and reactance of the line can be written as

$$\mathrm{P_o} = \frac{\mathrm{m_i} V_{gen} V_L Sin\phi}{\mathrm{X_L}} \tag{10}$$

The reactive output power of the inverter and the load current are given in equation 11 and 12 respectively.

$$\mathrm{P_{re}} = \mathrm{m_i} V_{gen} \frac{\mathrm{m_i} V_{gen} - V_L \cos\phi}{\mathrm{X_L}} \tag{11}$$

$$I_L = \frac{P_L}{V_{gen}\cos(\theta)} \tag{12}$$

DC-AC inverters are electronic devices used to produce AC power from low voltage DC energy that is stored in a battery. This is suitable for where the usual AC mains power is not available or appliances in caravans and mobile homes, and also running audio, video and computing equipment in remote areas. In this paper we have used the inverter for electric vehicle to avoid pollution, which can be used in any other fuel vehicle depends on the capacity needed. The inverters do their job by performing two main functions: first they convert the incoming DC into AC, and then they step up the resulting AC to mains voltage level with the help of a transformer.

The DC from the battery is converted into AC very simply, by using a bank of power MOSFETs that act as very efficient electronic switches. The positive voltage from the battery is connected to the center-tap of the transformer primary, while each MOSFET is connected between one end of the primary and the negative terminal of the battery. So by switching on the bank of MOSFETs, the battery current can be made to flow through the upper half of the primary to negative and lower half of the primary to negative simultaneously. As a result a corresponding AC voltage is induced in the transformer's secondary winding. The closed loop control system is used to maintain the correct voltage and power irrespective of the load. Certain loads will produce fluctuations and voltage spikes within the driving portion of the circuit, specifically around the MOSFETs. RC snubber circuit eliminates the voltage and current spikes and for protecting the MOSFETs zener diode is placed across to it.

3.3 Power Inverter Model

Power converters are employed in a variety of applications, including dc motor drives, power supplies, spacecraft power systems, computer etc. The dc-dc converter converts an unregulated DC voltage in to a regulated output voltage and the amplitude may differ from the input. In most of the applications, it is desired to incorporate a transformer into the switching converter, to obtain dc isolation between the converter input and output. The transformer size and weight vary inversely with frequency. The transformer present in the converter can create considerable progress; the transformer then operates at the converter with switching frequency of tens or hundreds of kilohertz. For increasing the frequency, modern transformers are made up of ferrite cores. These high frequencies lead to spectacularly reduce the transformer size

There are different ways of integrating transformer isolation into any dc-dc converter. Buck, boost, and buck-boost converters are frequently used converters. The fly back converter is an isolated version of the buck-boost converter. Here we are using the fly back converter for high voltage conversion. It is integrated with the controller for maintaining accuracy and robustness.

3.4 Speed Measurements and Control

Rotational speed measurement using magneto resistive sensors is achieved by counting reflection marks present in the rotating wheel. Magneto resistive sensors are characterized by the fact that the sensor is fixed and the output signal is generated by the bending of magnetic field lines according to the position of the target wheel. It will produce the signal amplitudes of 20 milli volts. The sensor output is high if the field is reflected from the reflecting material placed in the rotational part and all the other time it will be low. So the output is a continuous train of pulse given to the micro controller. The controller counts the number of pulses present in one minute and calculates the speed.

3.5 Fuzzy Logic Controller

The active power flow from the generator to the load is controlled though the flow of wind. The proposed fuzzy logic controller controls the active power if the vehicle is in different speed. The fuzzy controller consists of five different steps [3, 12] as shown in fig. 6.

Step (i) definition of input-output variables of controller
Step (ii) design of fuzzy control rule
Step (iii) fuzzification
Step (iv) inference
Step (v) defuzzification

The speed of the vehicle and the wind speed are proportional. For making the motor work at the optimal level a set of rule are made. The driver wants to press the pedal of acceleration at that time the speed of vehicle and the turbine speed are proportional. The charging state (CS) and position of pedal (POP) are the inputs and motor torque (T_M) is the output. The first input POP, which represents whether the vehicle is accelerating, decelerating, (ie: the wind speed is increasing and decreasing) or neither. Some typical rules for the fuzzy logic controller are given as follows:

- IF POP=PH and CS=H, then T_M =HH;
- IF POP=PL and CS=L, then T_M =H;
- IF POP=MH and CS=M, then T_M =H;
- IF POP=NM and CS=Z_o, then T_M =Z_o;

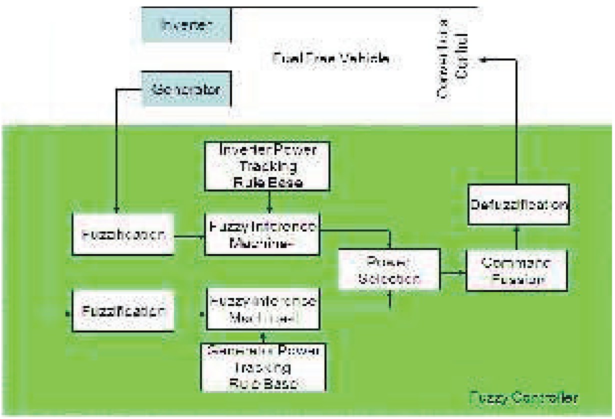


Fig. 6 Block diagram of fuzzy logic controller

Table 1. Linguistic control rule

POC		e				
		PH	PL	Zo	NL	NH
CS	PH	L	H	L	H	L
	PL	L	H	H	H	L
	Zo	Z	L	MH	L	Z
	NL	L	H	H	H	L
	NH	L	H	L	H	L

Where:

HH - very high; H- high; M- medium; MH- medium high; ML- medium low; L- low; LL- very low; PH- positive high; PM- positive medium; PL- positive low; Z_o- zero; NL- negative low; NM- negative medium; NH- negative high;

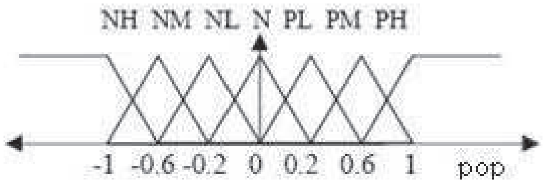


Fig. 7. Position of pedestal input

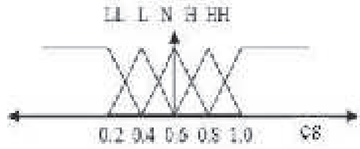


Fig. 8. Charging state input

The first input POP, which represent the speed of vehicle that is the vehicle is in accelerating, decelerating or both simultaneously. It is set to 1 then the acceleration pedal is fully pressed and it is set to -1 then braking pedal is fully pressed, as shown in fig.7. The second input determines weather the battery attains the maximum storage level or at low CS, as shown in fig. 8. The output is T_M, motor torque and is set to 1 for maximum and set at 0 for no torque as shown in fig. 9. In rule (1), the speed of vehicle is high

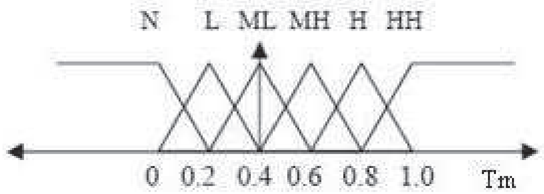


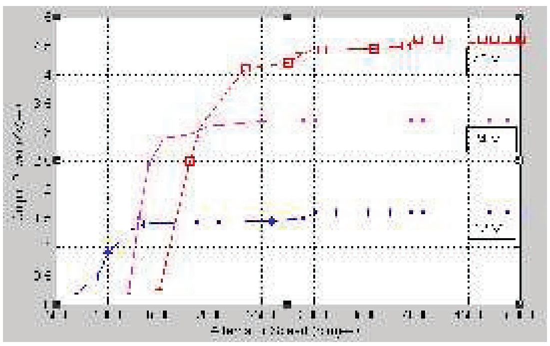
Fig. 9. Motor torque output

and CS is high, so the motor output torque is very high. In rule (2), the speed is moderate, and CS is low, so the motor output torque is high.

In rule (3), speed of the vehicle is high and CS is in a middle level, so torque is high. In rule (4), both the speed of vehicle and CS are zero and the motor torque output is 0. The fuzzy logic controller output is typically a change in duty ratio ΔD of the power converter. The linguistic variables assigned to ΔD for the different combinations of POP and CS as shown in Table.1.

4. Performance Evaluation

A DC power supply from the battery is used to energize the field winding with 5A. The output voltage of the alternator is varying based on the speed of the vehicle because the alternator is mounted on the vehicle.



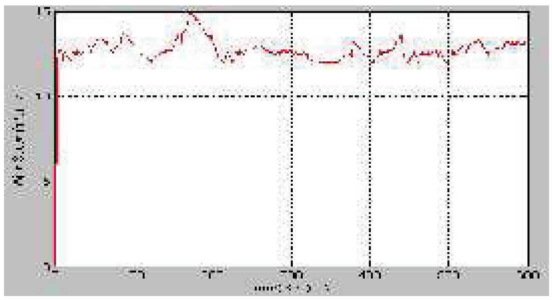


Fig. 10. Output power versus different speed

Fig. 11 Simultaneous changes in wind speed

A special type of blade is connected to the alternator shaft. The output voltage of alternator at different speed is shown in fig 10. The SMR plays an important role in maximizing the power at low speed by varying the output voltage, and also at high speed to limit the output voltage.
The fuzzy controller is interfaced with the drive and the control system so the output can be maintained almost constant. The wind direction can vary between day and night according to the location. Here we are incorporating the turbine on the bus so it will automatically rotate if the vehicle is in motion. The speed of the turbine and the vehicle speed are proportional and it is not always constant. The simultaneous changes in the wind (ie: change in speed of vehicle) and the extreme speed are shown in fig 11. The turbine output for various speed is as shown in fig 12. The vehicle contains 48V battery and the charging system automatically charging the battery. However, all the coils of the turbine is in parallel so it will produce enough voltage at low speed for charging. The fuzzy controller checks both the voltages of battery and generator. If the generator voltage level is less than the specified level then the controller switch over to battery supplies. The inverter is connected to all the coils and the measured and predicted power is shown in fig 13. The test points are plotted for 500 rpm of generator.

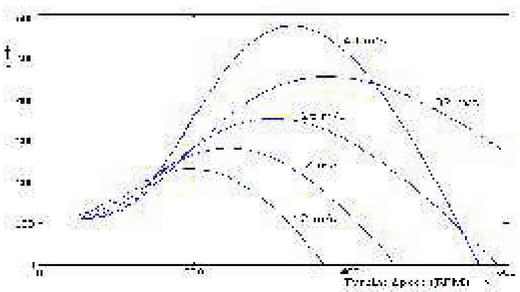


Fig. 12. Turbine output power for different speed scenario

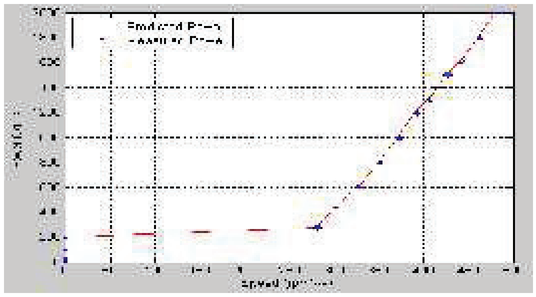
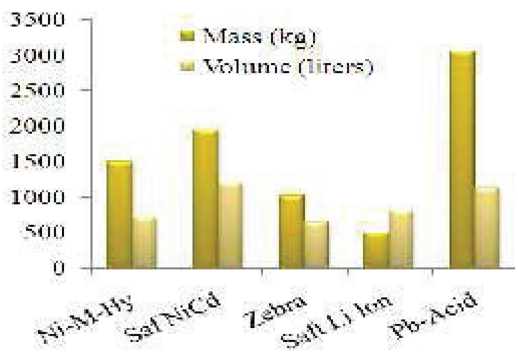


Fig. 13. Load Characteristics of inverter

Several manufacturers use advanced technology for producing batteries and these batteries remain relatively expensive. From all the batteries zebra provides lowest weight with sufficient energy storage. Fig 14 shows comparison between mass and volume of various battery technologies. Mass and volume of the zebra battery is less and it is higher than saft Li Ion. Also other parameters of this technology are much higher, so we can prefer zebra batteries for our proposed system.



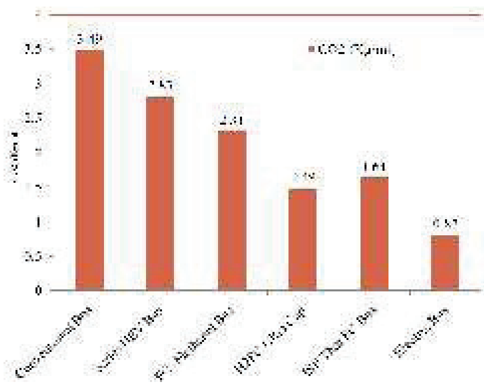


Fig. 14. Comparison of mass and volume for different batteries Fig. 15. Comparison of CO_2 emission for different vehicles

For calculating annual cost we are assuming annual mileage of 17,000 miles per year and 10 years life. Table 2 shows the comparison of life cycle cost of the proposed system with the other systems. It is clearly shown in the figure that the proposed system utilizing advanced battery (Zebra) and drive system reduces the cost. Number of batteries used in this system is reduced to half as compared to other system utilizing other battery technology [3], [8], [9]. Electric busses cleaner than fuel vehicles and particularly it can be 94 percentages fresh than diesel vehicles when considering with CO_2 emission [13]. Comparison of electric busses and other technologies are as shown in fig 15. Conventional buses that are using diesel will produce around 3.49 kg/miles. Electric vehicle produces less CO_2 emission than other technologies.

Parameters	Diesel (Rupees)	CNG (Rupees)	Lead-acid (Rupees)	Proposed (Rupees)
Vehicle life, years	10	10	10	10
Annual fuel cost	1,61,500	1,25,500	1,63,250	-
Annual maintenance cost	1,87,000	2,72,000	11,25,000	3,80,000
Battery life, years			1	6
Total annual cost	3,48,500	3,97,500	12,88,250	3,80,000

Table 2. Annual life cycle cost

5. Conclusion

Electric vehicles have a tremendous potential to improve energy efficiency and to provide pollution free world for our future generation. We are introducing a new approach and a set of design and control techniques for automotive alternators that yield dramatic improvements in performance and functionality as compared to conventional systems. In this paper we are using two alternators for reducing the number of batteries as a result the weight. The system automatically recharges the battery at the running time of the vehicle. So charging stations are not required for charging the batteries present in the vehicle. The fuzzy controller can handle the system efficiently if it is operating under battery mode or in direct mode of operation. Our system reduces the total weight of the system around 27 percentages and very less CO_2 emission compared with hybrid vehicles. We believe that the developing countries can adopt the system for pollution free environment.

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